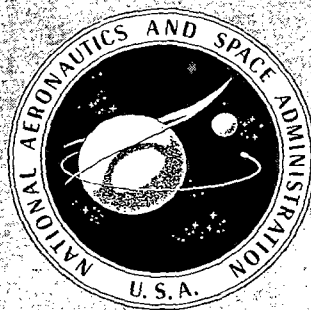


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ROCKET / NIMBUS
SOUNDER COMPARISON
(RNSC)



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ROCKET / NIMBUS SOUNDER COMPARISON (RNSC)

The report of a workshop meeting
held March 23-24, 1971,
at Wallops Station,
Wallops Island, Virginia



Scientific and Technical Information Office 1972
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Preface

Up to about two decades ago, our impressions of the atmospheric structure and behavior above 15 km were extremely limited. Since that time, high-altitude balloons, small meteorological rockets and larger rockets have been extending our knowledge to higher and higher altitudes. This new information, however, did not come cheaply nor without problems. It is rather well known, for example, that high-level radiosondes are plagued with errors brought on by radiation effects. Similarly, rocket measurements are affected by various errors, and much work has been done on analyzing and correcting for the errors inherent in each type of measurement. Inter-comparisons are a logical part of this endeavor.

In the last two years we have added an entirely new system to our high-altitude observational network, the satellite sounder. Even here, there are several instrumental types, all capable of yielding vertical temperature profiles within at least part of the stratosphere, and all with their own particular problem which could affect the accuracy of these data.

Since the upper atmosphere is being sounded by different methods, it seemed logical that a study be initiated regarding the compatibility of observational data. The Rocket-Nimbus Sounder Comparison experiment was conceived and planned in early 1970 with this point in mind. Even though rocket observations were to be taken at only one site, Wallops Island, at the time of Nimbus 3 and Nimbus 4 passage overhead, it was realized that the cooperation of many groups would be necessary if this unique experiment was to be successful. Thus, several planning meetings were held with the principals of the various satellite and rocket experiments as well as the personnel who would be involved in the operational aspects of the experiment. These meetings were conducted in a pronounced aura of cooperation.

The actual experiment was initiated during the summer of 1970. Following the gathering of an initial data sample and a preliminary scientific evaluation, it was decided to convene a "Workshop Meeting" in early spring. Everyone involved would be fully apprised of the results and general discussions could be held in order to determine the success of the experiment and decide what the next step should be if indeed a next step was necessary. This document represents a report of the Workshop Meeting.

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INTRODUCTION

Background

Meteorological rockets have helped increase our knowledge of the structure and behavior of the stratosphere and mesosphere. At the present time, relatively small rockets carrying radiosonde-type (rocketsonde) instrumentation can provide useful temperature and wind information between 25 and 60 km. Larger and more costly rockets, necessarily launched on a much less frequent basis, can sound the atmosphere to 80 km and higher.

The great advances of knowledge gained with the aid of rockets should not be underestimated; yet rocket-measuring systems have brought with them some new problems. Perhaps the most pressing problem is the specification of accuracies with which temperature can be measured using the various meteorological sounding rocket systems. The possibility of errors in rocketsonde measurements has been reinforced by studies performed with data gathered from nearly simultaneous measurements of different rocketsondes. These experiments have produced data which exhibit discrepancies that cannot be explained by any known type of atmospheric perturbation. Indeed, since the beginning of the coordinated launching program designed to acquire synoptic data with rocketsondes, a number of different systems have been used, each however with its own peculiar design characteristics. Several have been discarded because of their obvious inaccuracies. It is important to stress that, to the present, there has been no method developed which is capable of precisely determining the absolute accuracy of any temperature measured while the sonde is in the environment in which it was designed to operate.

The development of satellite-borne equipment capable of remotely sensing radiation temperature within various layers of the earth's atmosphere has also progressed rapidly within the last several years. We are now at the point where experimental satellites, such as Nimbus 3 and 4, carry various experimental equipment whose measurements make possible the derivation of temperature profiles from the earth's surface to well up within the stratosphere. Thus, we may be on the verge of utilizing this entirely new concept of atmospheric sensing which holds the promise of at least supplementing our present-day in situ methods. Again, there exists a similar problem of determining the accuracy with which satellite instrumentation can sense radiation temperature within a given layer of the atmosphere.

With the above comments in mind, it is natural that the question of data compatibility should assume a place of importance. Primarily, it is the compatibility between data derived from the satellite remote sensing devices and data measured by in situ soundings, characterized by the radiosonde and rocketsonde. The new set of satellite-derived data could add another very large dimension to the present-day dilemma brought on by the incompatibilities among various types of radiosondes,

among the various types of rocketsondes, and between the radiosondes and rocketsondes.

Compatibility studies involving radiosonde and satellite data for some levels within the troposphere and lower stratosphere are already under way within the National Oceanic and Atmospheric Administration, and preliminary results have been generally encouraging.

It is in the stratosphere that the satellite data become extremely useful, especially since the radiation measurements are not, for example, degraded by the existence of clouds in the area being sensed. It is also at the higher altitudes that the meteorologist needs data, since radiosondes are known to be inaccurate, if reports exist at all, and rocketsonde measurements cannot be supplied in the necessary numbers. Thus, several questions come to mind immediately. Are the satellite-derived temperatures and rocketsonde-measured temperatures compatible? What impact will the satellite radiation measurements have on the worldwide network of meteorological rocket stations?

In order to at least partially answer the questions asked above, and in anticipation of the requirement for temperature verification data from meteorological rockets, NASA Wallops Station initiated a plan whereby rocketsondes and radiosondes were to be launched at Wallops Island in approximate conjunction with satellite overflights. This experiment has been named the Rocket-Nimbus Sounder Comparisons.

The Overall Experiment

The basic experiment was planned in April 1970. A feasibility study had already shown that meaningful comparisons could be made between in situ measurements and satellite data, providing careful planning and strict experimental controls could be applied. A most important aspect of any such study is the requirement that all systems sense the same portion of the atmosphere at the same time. The difficulties of using a radiosonde, rocketsonde, and a larger meteorological rocket to provide a single vertical profile which is representative of a given vertical atmospheric column are obvious. Add the requirement for a satellite to sense the same column at the same time and the situation is further complicated.

During winter the horizontal temperature gradients at stratospheric levels can be rather intense. On the other hand, summertime gradients are always very weak. In fact, the entire temperature difference from polar regions to the equator may be as small as 15°C. Clearly, the summertime, with its lack of large meteorological variations at stratospheric levels, would be the prime season in which to more nearly satisfy the sensing requirements. The complex of launch facilities at NASA Wallops Station, Virginia, appeared to be ideal for carrying out the in situ type measurements. A prime advantage is that the station can launch all necessary types of rockets within

relatively short time periods and has sufficient equipment to track a number of instruments at one time. Thus, there should be no major problems in satisfying the requirement that the in situ observations must be made within the same time frame.

With the above in mind, the experiment was planned for the summer of 1970. The major objectives were to determine:

- a. The compatibility among meteorological satellite data derived from the various satellite instruments: The Satellite Infrared Spectrometers (SIRS-A and SIRS-B), the Infrared Interferometer Spectrometer (IRIS), and the Selective Chopper Radiometer (SCR).
- b. The compatibility among the temperature measurements of radiosondes, meteorological rocketsondes, acoustic grenade, and pitot-probe soundings.
- c. The utility of combining satellite data and rocket data for atmospheric research in the stratosphere and mesosphere.

Since the Nimbus satellites are testing methods to monitor the spatial distribution of atmospheric ozone, it appeared feasible to gather ozone measurements coincident with balloon-borne radiosondes. Wallops has the special capability of taking ground-based observations of the total ozone (via Dobson Spectrophotometer) and measuring the vertical distribution with a combined ozonesonde-radiosonde instrument. The accomplished gathering of ozone measurements was classified as a secondary objective.

Scheduling of Observations

The ephemerides associated with Nimbus 3 and 4 confirmed that both satellites passed near Wallops Island in daylight, fortunately on some occasions within a very short time period of each other. On these occasions one set of rocket observations, properly timed, could be used for comparison with all of the available satellite instrumentation. Otherwise the Nimbus 4 satellite was considered the prime vehicle. The acceptable horizontal distances between the rocket observations and the point of satellite sensing were set at less than $\pm 5^\circ$ of longitude as the satellite passed the station from southeast to northwest. Time differentials were set at one hour maximum. Additional plans called for turning off the side-scan sequence in SIRS-B (Nimbus 4) when necessary, so that the system would be sensing straight down as with the other instrumentation on board.

Scheduling of in situ and ground-based observations was dependent on the time of satellite passage. The following general schedules were used:

- a. Combined rawinsonde-ozonesonde sounding was begun 3 hours before satellite passage. The balloon rises at approximately 330 meters per minute and for the experiment was expected to reach an altitude of 30 km.
- b. In every case an Arcas rocket was scheduled for launch 15 minutes prior to the passage of the satellite. On a selected basis, Datasondes¹ were scheduled for launching 10 minutes following satellite passage.
- c. The larger grenade and/or pitot-probe rocket experiments were planned for launching at the coincident passages of Nimbus 3 and 4 satellites. Weather and range constraints permitted these launches only during the weeks of June 21, August 2, and September 13. The complete meteorological rocketsonde schedule was to be maintained during these specific periods. One prerequisite for the research rocket launch (grenade or pitot probe), however, was that a good temperature profile be obtained from the meteorological rocketsonde.

Data Sample Obtained for Comparisons

From June 8 through September 23, 1970, in situ measurements were obtained coincidentally with satellite passages on 33 occasions. Fortunately, there were additional pre-experimental data obtained primarily during 1969, which also satisfied the overall criteria. Table 1 indicates the number of satellite and rocket observations available for comparison.

A workshop type meeting was planned for early spring of 1971 in order to discuss preliminary results from studies accomplished with the data noted above. Presentations would be made by the various investigators, operations experts and interested parties. This meeting would lead to further plans on the conduct of this and similar experiments.

Workshop Meeting

The Rocket-Nimbus Sounder Comparison (RNSC) working meeting was held at Wallops Island, Virginia, on March 23 and 24, 1971. Invitations were accorded to a number of experimenters, principal and scientific investigators, Wallops Range personnel and other interested parties. The workshop was hosted by Mr. R. L. Krieger, Director of NASA Wallops Station and the Chairman was Dr. M. Tepper, Director of Meteorology, Office of Space Science and Applications,

¹The National Aeronautics and Space Administration does not approve, recommend, or endorse any product except for its own use, and the evaluation and test results shall not be used in advertising, sales promotion, or to indicate in any manner, either implicitly or explicitly, endorsement by the National Aeronautics and Space Administration.

TABLE 1
Number of Paired Satellite and Rocket Observations
Available for Comparison

	DI ¹	DII ²	ARC ³	GREN ⁴	PITOT ⁵
SIRS A*	4	-	14	-	-
SIRS A	3	5	10	2	2
SIRS B	9	13	20	3	3
IRIS	7	9	16	3	3
SCR	5	9	16	3	3

*Pre-experimental data

¹Datasonde I (bead thermistor flush against mount)

²Datasonde II (bead thermistor off mount)

³Arcasonde 1A

⁴Grenade experiment

⁵Pitot experiment

NASA. A complete list of attendees and affiliations is included in the Appendix, along with the Agenda.

From the Agenda, which was followed with only minor revisions, it can be seen that much emphasis was placed on in-depth descriptions of the various rocket and satellite systems used for the experiment. The fundamental aspects of these descriptions will be given here. The manager of the experiment, J. F. Spurling, presented the Conduct of the Experiment, and much of the information has been given in the Introduction.

ROCKET SOUNDING SYSTEMS

Arcas and Boosted-Dart

The meteorological rocketsondes used for the experiment were the Arcasonde and Datasonde systems. F. J. Schmidlin gave an account of the individual sounding techniques together with information on the method of using lower-altitude data from the supporting radiosonde ascent to acquire pressure (and density) by hydrostatic integration of the rocketsonde temperature profile. Error sources in the rocketsonde

and radiosonde instruments were mentioned, while emphasizing the repeatability characteristics of the small rocket soundings.

Although the Arcasonde provides usable temperature measurements from about 60 to 15 km, the Arcas motor's wind sensitivity, cost, and size have not been desirable features for routine measurements. These problems have justified development of simpler systems such as the Datasonde. The relatively light weight, low cost Datasonde was developed for the Air Force and is capable of being launched during high surface wind conditions. Its Loki motor burns for about 2 seconds of flight, compared with about 30 seconds for the Arcas, yet reaches an altitude near 60 km.

The Arcasonde and Datasonde instruments descend via parachute from apogee while they transmit at 1680 MHz and are automatically tracked by the Ground Meteorological Detector (GMD). Direct readout of rocketsonde height from the GMD is not available since the rocketsondes do not carry pressure elements as do the radiosondes. Thus, radar tracking is required (see Fig. 1 for Arcasonde flight sequence).

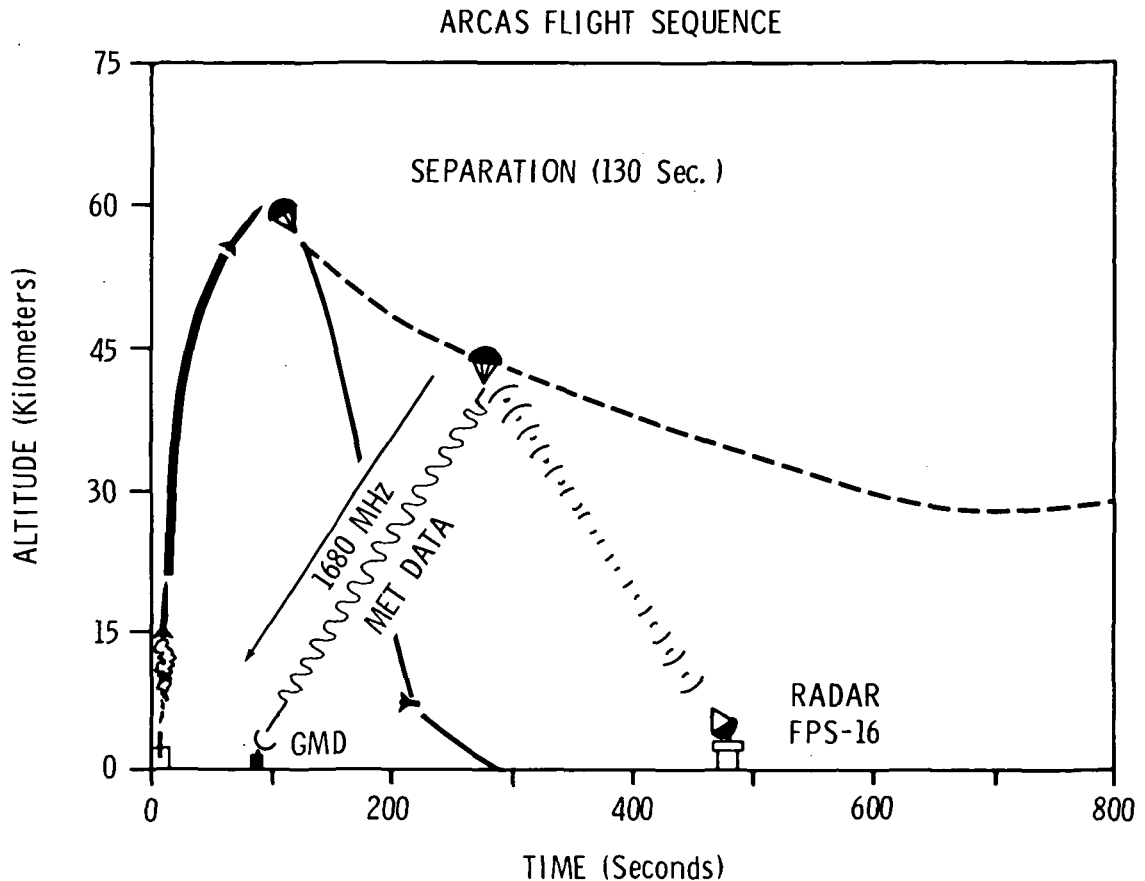


Figure 1. Arcas Flight Sequence.

All rocketsonde observations which measure thermodynamics require a support radiosonde observation to provide a foundation for hydrostatic computations. Reduction of the radiosonde data is done in accordance with the current Federal Meteorological Handbook, while rocketsonde data reduction is accomplished using techniques developed specifically at NASA Wallops. The selection of temperature data from GMD recorder chart is based on selecting points when significant changes in the temperature lapse rate occur. For example, for a rocketsonde observation a point is tested against a straight line connecting adjacent points, and if this point departs by 2°C or more from the line, the change is considered significant. Altitudes of the significant temperature points are obtained from the radar plotboard charts, which provide a record of altitude and time.

Although the reliabilities of rocketsonde systems have improved considerably, there exists an uncertainty in the accuracy of the measured temperatures. Most of the errors existing in the data stem from sensor, telemetry, receiving, and recording, and subjective evaluation problems. Systematic errors usually become apparent after a large data sample has been collected. They frequently are caused by general design problems. This type of error can usually be compensated for by corrections to the measured data. On the other hand, random instrumental errors may be found in any particular observation, but will vary from sounding to sounding, thus not permitting data to be corrected unless the source of error for that particular instrument is known.

Many different experiments have been carried out to determine the various systematic and random types of instrumental errors. One such experiment took place in June 1969, when a series of twelve Datasondes was launched in pairs (Ref. 1) close in time and space. The object was to demonstrate the repeatability of this instrument. Although it was later discovered that the mounting of the thermistor (thermistor bead flush against mylar mount) on all such instruments caused temperature readings higher than normally expected, valuable information was nevertheless gained from the experiment. In order to control the experiment all bead thermistors were inspected several times. Only one pair of instruments yielded anomalous differences and when the inspection notes were reviewed, it was found that one instrument of this pair contained a thermistor with a cracked glass coating. As a result of these inspections and tests it was concluded that such damage can affect the physical characteristics of the sensor and thus its measuring capability. Similar testing has been done for the Arcasonde. General results indicate that the small bead thermistor used as a sensor can reliably observe the atmosphere up to about 55 or 60 km. However, as much as we realize the thermistor's usefulness, we also realize its limitations.

Possible error sources of the thermistor lie mainly in its radiation characteristics, heat conduction from the relatively hot sonde body through the mounting posts and leads, dynamic heating caused by the high fall velocities experienced by the instrument, and poor thermodynamic equilibrium between it and the atmosphere. Because the values of many of these parameters are experimental, the accuracy with which the system can measure "true" air temperature is uncertain.

Meteorological Rocketsonde Temperature Corrections

The next presentation was a description by F. L. Staffanson of studies to derive mathematical models for rocketsonde sensors, and from these models to generate proper corrections for measured Arcasonde temperatures. Temperature corrections for the Arcasonde 1A have been determined and are based on a model in which the film-mounted thermistor temperature sensor is represented as two thermal masses coupled by a relatively fast-reacting conductor. The thermistor bead and film mount, together with the connecting wire, each respond to the air flow, the radiation environment, and conductive boundary conditions according to their respective properties (Ref. 2).

It was found that the sensor temperature at any point in the sounding depends on the values of 40 parameters. These parameters may be divided into two classes: (1) those 19 parameters which vary from point to point in the flight, such as radiation geometric factors with respect to the sun, convective heat transfer coefficient, and thermal recovery factors of the bead, wire, and film mount, and (2) those 21 parameters whose true value and assumed value, and therefore uncertainties, are considered fixed over the flight, such as diameter and length of the wire, the thickness of the film, and the thermal conductivity of the wire.

The computer-applied correction scheme also computes the uncertainties of the corrections. Uncertainty was defined to be two standard deviations based on the supposition that two sigma is a practical boundary within which to expect the true value. Estimated values for the 40 parameters and their respective uncertainties are obtained from:

- a. Specific laboratory measurements (such as sensor emissivity and wire length).
- b. Inflight measurements (such as airspeed).
- c. Past experimental data (such as the Earth albedo).

Derivation of uncertainties for the Arcasonde 1A is described in Ref. 3.

Temperature profiles were given for 10 soundings. It was seen that uncertainty increases rapidly with altitude due to the decrease of convective coupling with the atmosphere, while the radiation input remains constant. The uncertainties were about 1° Kelvin from 25 to 40 km, about 3° at 50 km and about 8° at 60 km.

The Acoustic Grenade Technique

J. Theon presented information on the acoustic grenade technique, which has been routinely employed to obtain vertical profiles of temperature and wind in the upper atmosphere for more than 15 years. The value of the technique lies in its freedom from the problems normally associated with immersion temperature sensors at high altitudes, such as time response, radiation errors, aerodynamic heating, etc. However, a limitation inherent in this technique is the restriction of vertical resolution.

The technique consists of a rocket-launched payload which detonates high explosive charges at programmed intervals along the ascending portion of its trajectory (Fig. 2). The positions and time of each explosion and the arrival times of the generated sound waves, measured by an array of special microphones on the ground, determine the speed of sound in each layer (2-5 km thick) bounded by consecutive grenades. The speed of sound in a gas is related to its absolute temperature (Ref. 4).

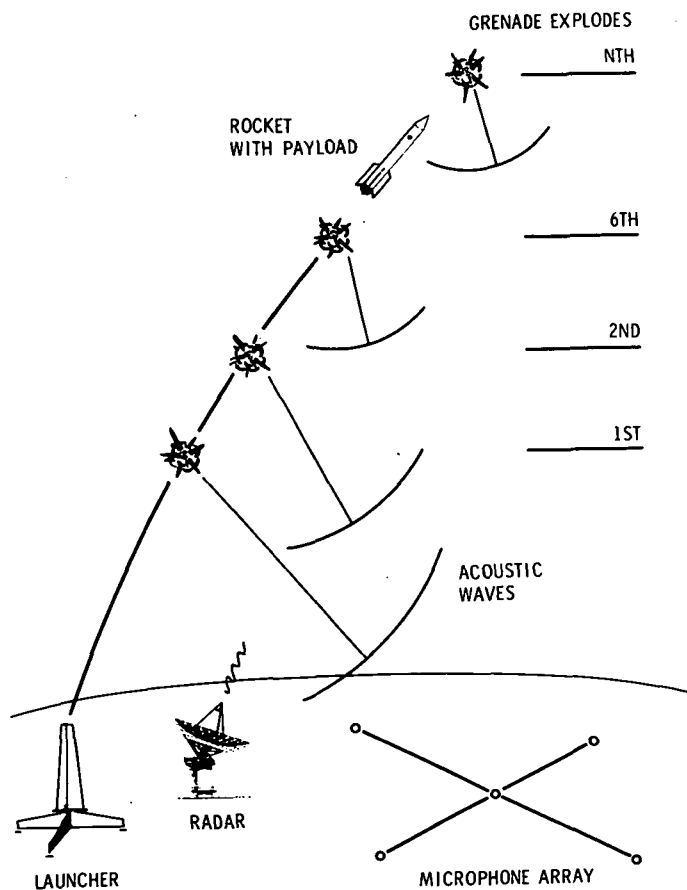


Figure 2. Schematic of Acoustic Grenade Technique.

The measured parameters required for the grenade technique are listed in Table 2. Each, except the positions of the microphones, varies not only from one grenade to the next, but from one sounding to the next. In addition, each is subject to some error in its determination, and the effect on the temperature profile is indirect and often complex (Ref. 5, 6).

TABLE 2

Measurements Involved in the Acoustic Grenade Technique

1. Burst Times of Grenades
 2. Burst Positions of Grenades
 3. Arrival Times of Acoustic Waves at Each Microphone
 4. Positions of Microphones
-

Table 3 lists the sources which contribute to the temperature error. Errors in determining the burst times of grenades contribute to the total error in the travel time of the acoustic wave to the ground and also affect the determination of the burst position of the grenade. These errors are usually small (less than half a degree).

TABLE 3

Sources of Error in the Acoustic Grenade Technique

1. Burst Times of Grenades
2. Burst Positions of Grenades
3. Arrival Times of Acoustic Waves at Each Microphone
4. Positions of Microphones
5. Assumptions Made in Analytical Solution
 - a. No vertical wind
 - b. Meteorological parameters are horizontally homogeneous
 - c. Finite amplitude propagation correction

Burst position errors depend on the system used to track the rocket, and even though their absolute value may be in error by as much as 20 meters at 50 km, it is the relative position of one grenade to another which is most important in affecting the temperature profile.

Sound ranging errors are historically the largest source of error. However, the error in arrival times of the acoustic waves at the microphones has been reduced considerably in recent years by increasing the size of the microphone arrays. In the soundings under discussion, the contribution of the sound ranging errors is less than 1.5°K below 50 km.

When burst position errors are calculated, they are similar in magnitude to the sound ranging errors below 50 km. Combining these two sources of error increases the total error, but typical values are on the order of $1\text{--}2^{\circ}\text{K}$.

The errors which arise from assumptions made in the analytical solution are difficult to assess. In addition, a question which most often arises concerns the neglect of vertical motion in the atmosphere. Vertical winds do generate errors, but these are negligible in most cases unless the vertical velocity reaches magnitudes of several m sec^{-1} . This is unlikely at altitudes below 50 km except under the most violent weather conditions, and then it is limited to a small area (e.g., thunderstorm activity). To date, no soundings have been made under such conditions.

A grenade sounding conducted during the experiment on September 17 was launched within 16 minutes of a pitot sounding, which makes it useful for comparative purposes. The pitot data were averaged over the same layers as the grenade data and the results are plotted in Fig. 3. The average difference between the two techniques is less than 5°K over the altitude range shown. The grenade results are consistently warmer, but if the estimated errors for the pitot probe (3°K) are plotted with the standard deviation for the grenade results, the unexplained difference is on the order of 1°K . The two rockets were not launched at the exact same time nor did they traverse the same flight path. Therefore, random variability of the atmosphere may have contributed to this difference.

Pitot-Probe Experiment

The pitot-probe technique was described by J. Horvath. This system utilizes pressure sensors to measure the impact pressure at the forward end of the rocket payload as it ascends (Fig. 4). Its purpose is to measure the neutral particle density in the atmospheric layer between 30 and 120 km. The interpretation of impact pressure data in terms of atmospheric density follows from basic aerodynamic theory (Ref. 7, 8).

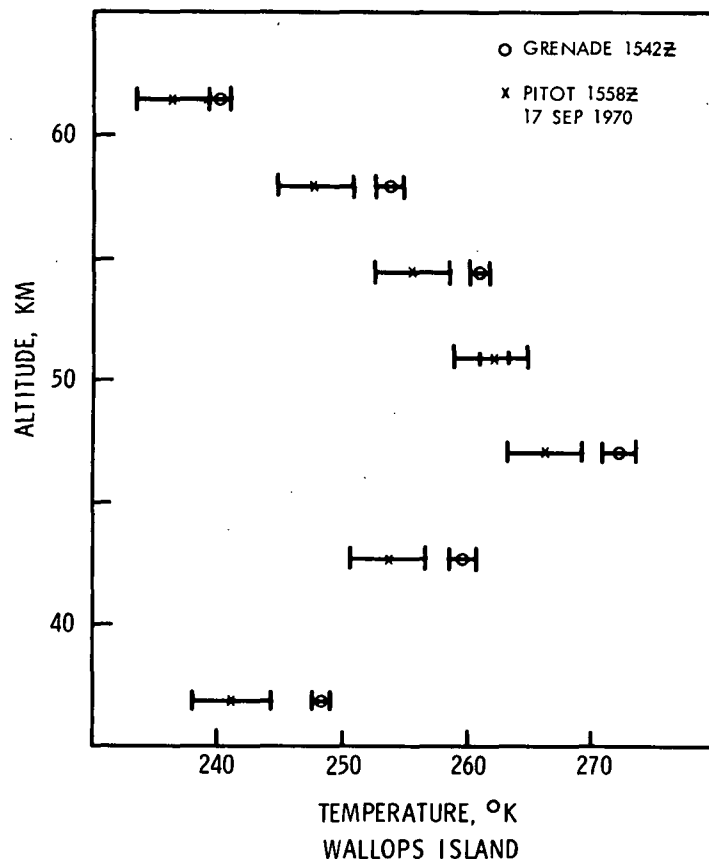


Figure 3. Comparison of Grenade and Averaged Pitot Temperature Profiles.

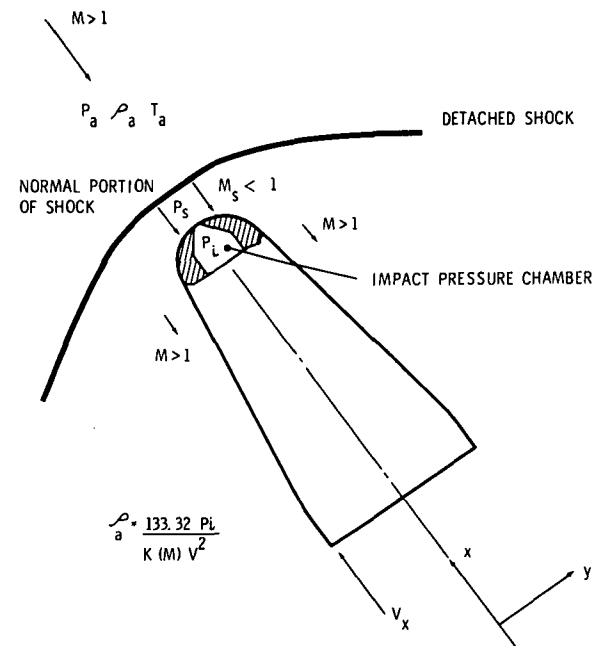


Figure 4. The Rayleigh Pitot Tube Equation Model.

The parameters shown are defined as follows: ambient density (ρ_a), temperature (T_a), pressure (P_a), pressure directly behind the shock front P_s , impact pressure sensed at the orifice (P_i), Mach number M_s , free stream Mach number (M), vehicle or flow velocity (V), and $K(M)$ is a Mach number-dependent factor relating the ambient density to the measured impact pressure.

An error analysis for density was provided in the discussion. Some error may be injected by the aerodynamic theory. For example, a major restriction is in the assumption that the shock wave will always maintain a given relationship to the probe. In addition, the orifice of the impact pressure chamber is theoretically assumed to be located at a point, when in fact it has a finite size. Additional error may arise due to the idealized assumption that the atmospheric gas, composed of diatomic molecules, adjusts its internal energy, instantaneously, to temperature changes.

Errors may also be brought on by impact sensing response. The combined net time response of the impact pressure gauge and the pressure lag within the pressure chamber to sense ideal impact pressure is less than 15 msec. For the velocities attained during pitot probe flights, together with the resulting pressure scale heights, the maximum error is found to be 0.3 percent.

The device used to sense impact pressure is a radioactive ionization gauge. Several standards used for calibrating this device may be classified as static or dynamic. The repeatabilities of static or dynamic calibrations have been shown to be within 0.5 percent.

The velocity and position or altitude are considered in trajectory-type errors. For the Wallops observations the velocity differences between observations appeared to be less than 2 m/sec. The maximum altitude differences were 20 meters. These differences would result in density errors of less than 0.25 and 0.40 percent, respectively.

One additional error may be brought on by the effects of atmospheric winds. The actual fluid flow should ideally include the effects of horizontal winds, which may inject a density error of less than 0.25 percent.

Taking these errors into account, the total pitot probe error estimate is given as $+0.6 \pm 0.7$ percent. These estimates, however, do not include those errors that may arise from the telemetry or data reduction.

SATELLITE SOUNDING SYSTEMS

Satellite Infrared Spectrometer (SIRS)

Information on the SIRS experiments was given by D. Wark and J. Lienesch (Ref. 9, 10, 11). Two infrared grating spectrometers have been developed for the Nimbus Meteorological Satellite Program for indirectly sensing vertical atmospheric temperature and humidity profiles from space. SIRS-A has 8 channels, 7 of which are measuring in the $15\mu\text{m}$ CO_2 band and 1 measuring in the $11\mu\text{m}$ window (Fig. 5).

SIRS-B, in addition to 8 channels similar to the ones on SIRS-A, has 6 spectral intervals that measure atmospheric water vapor.

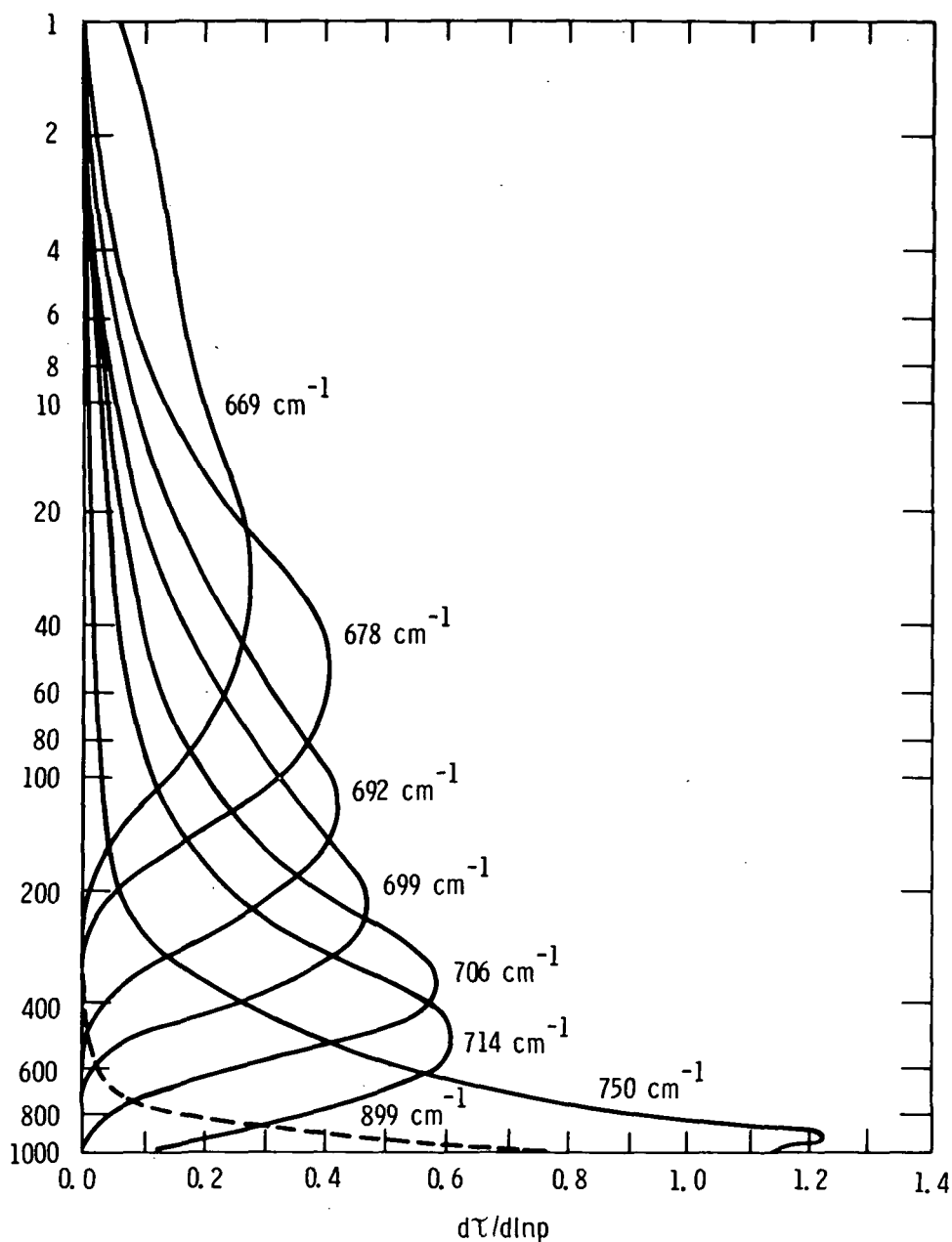


Figure 5. Derivative of Transmittance with Respect to the Logarithm of Pressure for each SIRS-A Spectral Interval of Observation.

Of interest for measurement in the stratosphere are Channels 6, 7, and 8. However, Channel 6 on SIRS-B failed prematurely and relatively little information from it is available. Of prime importance are Channel 7, centered at 679.9 cm^{-1} with a weighting curve peak at about 50 mb (20 km), and Channel 8, centered at 668.7 cm^{-1} with a weighting curve peak at 30 mb (24 km).

The in-flight calibrations of the two instruments are essentially quite similar, and include a radiance calibration and a spectral calibration. The radiance calibration is made by switching the view of the detectors first to space and then to a black body whose temperature is accurately measured. The spectral calibration is an integral part of the radiance calibration. On SIRS-B, calibrations are made at intervals of every 2 orbits while the spacecraft is over the Antarctic. On SIRS-A, calibrations were normally made once per 256 minutes (once every 2-1/2 orbits).

A time history plot of SIRS-A Channels 6, 7, and 8 indicated that the SIRS-A calibration had slowly degraded with time (less than 0.5%) during the Wallops Island Comparison Experiment. On the other hand, SIRS-B calibrations for Channels 7 and 8 exhibited no apparent shifts.

The weighting function can be defined as the derivative of the transmittance by CO_2 , and whatever other constituents are absorbing in the atmosphere, with respect to the logarithm of pressure.

There are presently two techniques for solving the integral equations of radiative transfer; a statistical technique and a minimum information solution technique. The statistical technique is based upon measurements by radiosondes, rocketsondes and grenadesondes. The minimum information solution is similar to the statistical solution, but employs a solution matrix of equal variances and zero covariances coupled with an arbitrary initial guess. The former solution was used during the Wallops Comparison Experiment.

Ozone has a significant effect on the temperature retrieval scheme. If this parameter is omitted from the computations, errors of about 5 percent can be induced in the retrieved temperatures. However, the effects of clouds, which are considerable at tropospheric levels, are not significant in Channels 7 and 8.

A SIRS-B retrieval for June 10, 1970, is shown in Fig. 6. This was obtained using the minimum information solution. In this case the radiosonde/rocketsonde observations were used as the "guess" profile, whose shape is retained in the solution. As indicated, the rocket used was a Datasonde I (i.e. bead down). This comparison shows that this rocket sounding yielded higher temperatures than the SIRS retrievals.

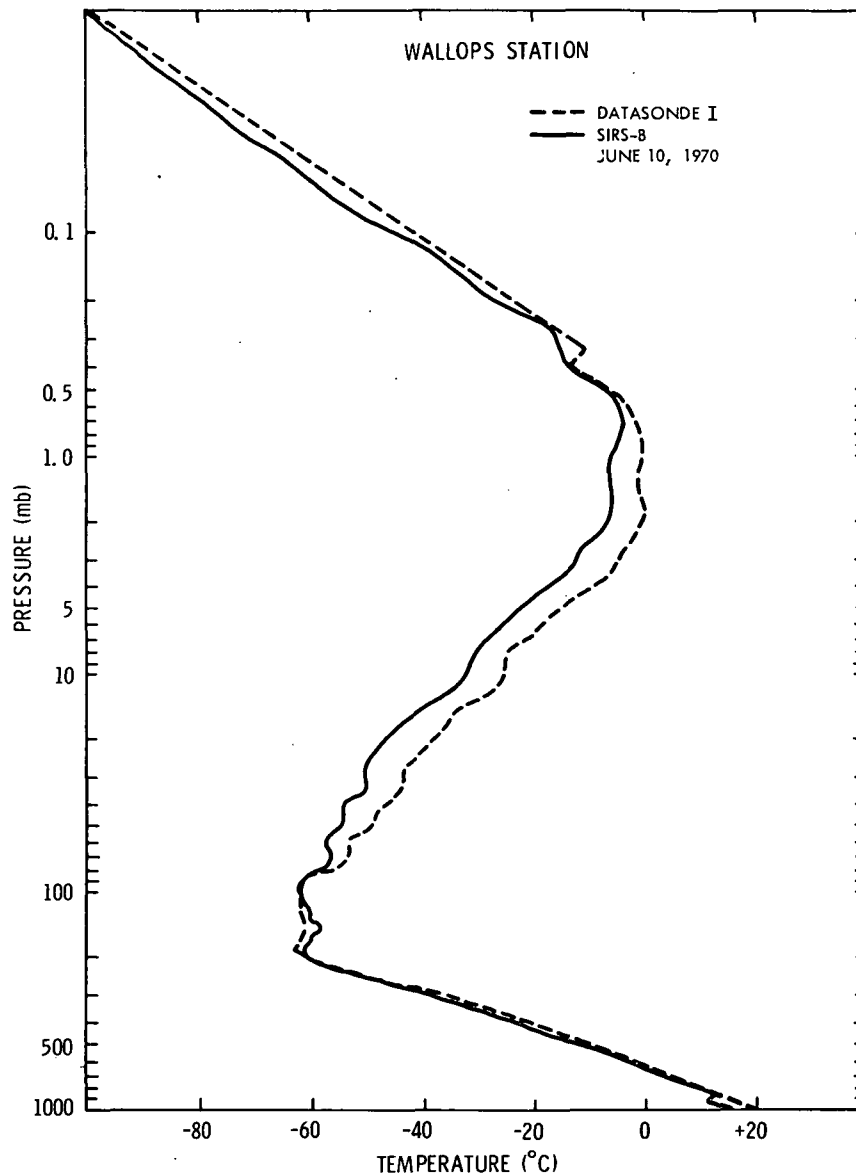


Figure 6. A SIRS-B Retrieval on June 10, 1970, using the Minimum Information Solution. Concurrent radiosonde/rocketsonde observations at Wallops Island, Va., were used as the "guess" profile.

Infrared Interferometer Spectrometer (IRIS)

R. Conrath described the IRIS instruments on board Nimbus 3 and Nimbus 4. These nadir sounders measure the thermal emission spectra of the earth between 400 cm^{-1} and 1600 cm^{-1} (Ref. 12, 13, 14). The IRIS-D on Nimbus 4 has a higher spectral resolution (2.8 cm^{-1}) than either the earlier IRIS-B on Nimbus 3 or the SIRS instruments, and is capable of providing vertical profiles of temperature, water vapor and ozone. For temperature retrievals, sixteen spectral intervals are used, although some are redundant. The weighting functions for the sixteen channels are shown in Fig. 7. Of most interest is Channel 1 which is centered near 30 mb and is influenced by the entire stratospheric layer.

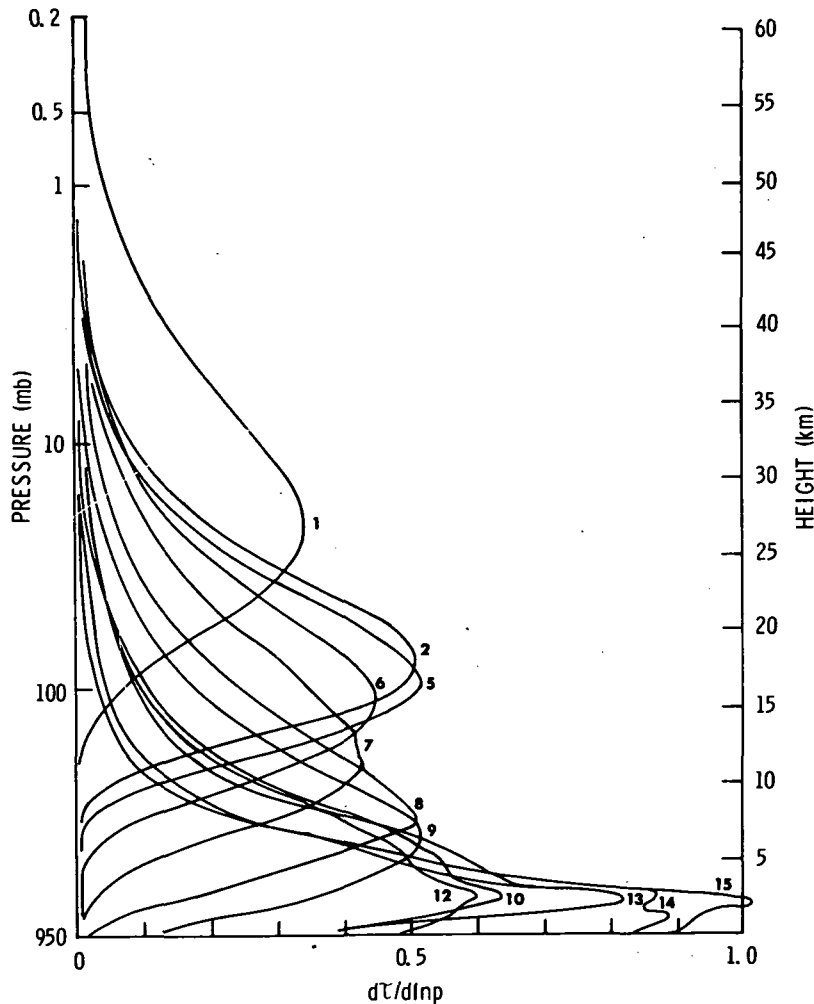


Figure 7. IRIS Weighting Functions $dt/d\tau(\ln p)$. A total of 16 spectral intervals located in the region between 667 cm^{-1} and 758 cm^{-1} were employed in the retrievals. Weighting functions for several of these intervals are shown.

Temperature profiles can be obtained from three different inversion methods, which have been found to produce essentially the same results. The Wallops Island data were derived by using the so-called minimum information method (Ref. 15). The atmospheric transmittances employed were generated using an empirical model in which the parameters were adjusted by least squares fitting of measured radiances to radiances calculated from near-simultaneous radiosonde measurements. At the upper levels, at higher altitudes than the normal radiosonde ascents, extrapolations parallel to the standard atmosphere were utilized. Temperature retrievals were obtained on 25 days during the June-September 1970 intercomparison period for these; monthly mean profiles were employed as first-guess estimated. The average of several sample retrievals for Wallops Island were shown alongside the observed raob-rocketsonde profiles (e.g. Fig. 8), indicating agreement within about 5°C below 10 mb, 9°C above. The mean difference based on 18 nearly cloud-free profiles was at most about 6° (at 2 mb), with a standard deviation of about 2-5° between the 1000 and 0.1 mb levels.

Selective Chopper Radiometer (SCR)

J. Houghton described the SCR experiment on board Nimbus 4 (Ref. 16, 17, 18, 19). The weighting functions of Channels 1, 2, 3, 4 (sometimes denoted A, B, C, D) peak respectively at pressures 2 mb (42 km), 15 mb (27 km), 60 mb (19 km), and 100 mb (16 km) (weighting functions of all six channels are shown in Fig. 9). These weighting functions have been derived from direct measurements in the laboratory on the SCR instrument before launch, to which measurements, theoretical corrections for atmospheric conditions have been applied. No adjustments to these weighting functions have been made to obtain a better fit with radiosondes or rocketsondes. The limitations on accuracy of the SCR radiance measurements, which are mainly brought on by problems in calibration, include:

- a. Noise giving probably random error of about ± 2 radiance units² in Channel 1, \pm radiance units in Channel 2 and much less in the other channels.
- b. Temperature variation of gain giving a probably random error of about ± 1 radiance unit in Channel 1 and ± 0.5 radiance unit in Channel 2, and negligible error in the other channels.
- c. Variation of balance in Channels 1 and 2. Channel 1 has been nearly in balance so that corrections can be made with a probable error of ± 0.5 radiance unit. Channel 2 has gone well away from balance and at orbit 2000 was nearly 20 percent out of balance. The correction for imbalance involves the difference in radiance between Channels 2 and 3 - typically 10-15 radiance units for Wallops cases. The correction can be made with a probable error of well under 1 radiance unit.

²Radiance unit is $\text{ergs cm}^{-2} \text{ ster}^{-1} \text{ sec}^{-1} (\text{cm}^{-1})^{-1}$. This may also be referred to as $\text{ergs}/$.

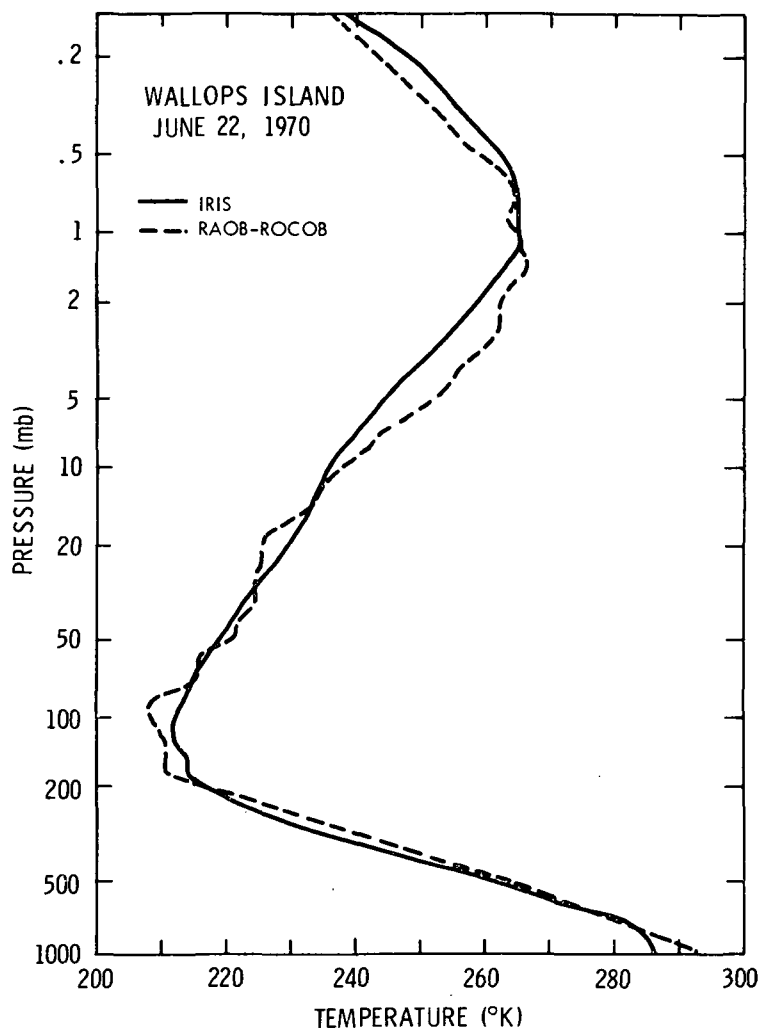


Figure 8. Sample IRIS Retrieval for June 22, 1970, and Concurrent Radiosonde/Rocketsonde Observation for Wallops Island, Va.

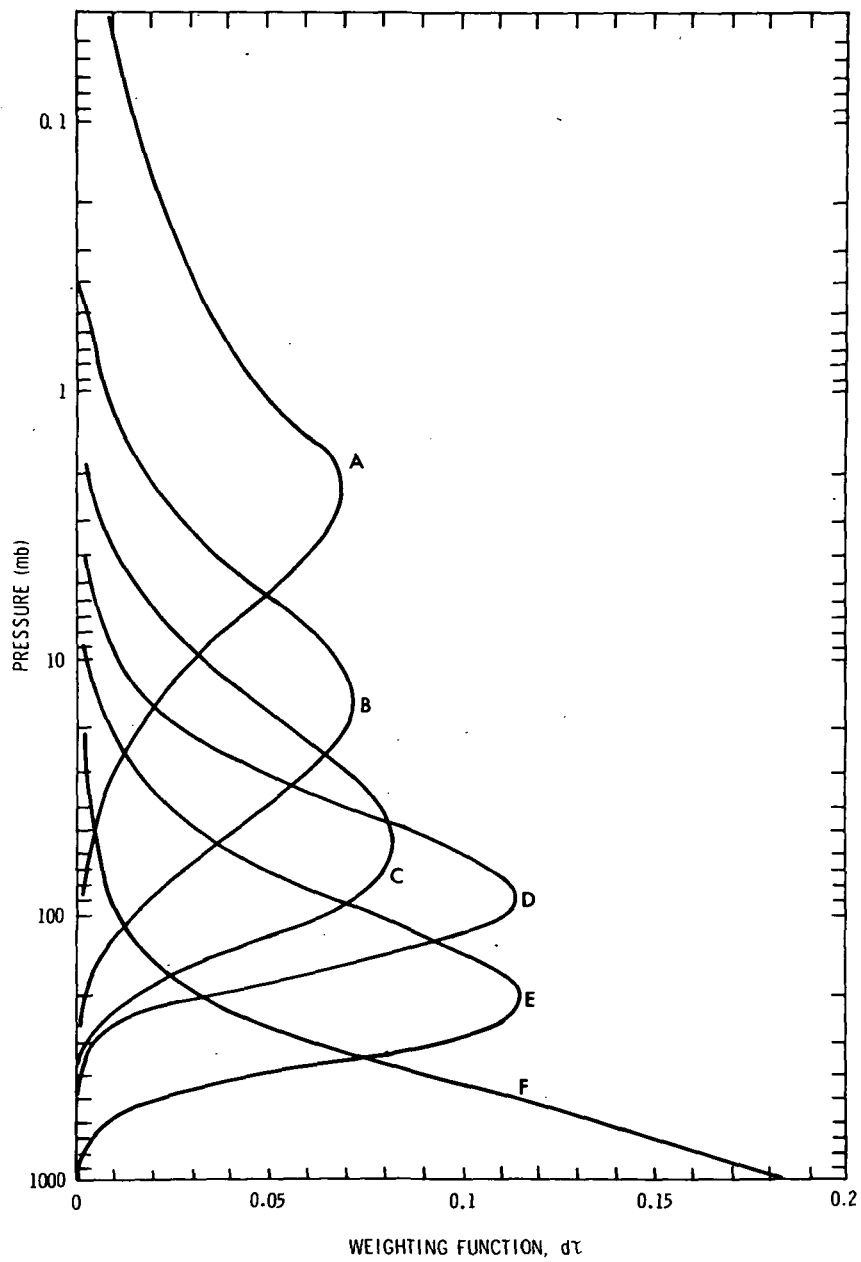


Figure 9. SCR Weighting Functions.

- d. Accuracy of internal calibration. This was checked thoroughly during thermal vacuum. Comparison between the internal target and a standard black body showed differences in nearly all cases of $< 1^{\circ}\text{C}$.
- e. Lack of knowledge of offset. This is a problem which arises because of stray radiation which occurs in Channels 1, 2, 4, 6 (A, B, D, F). Careful calibration was carried out in thermal vacuum and no appreciable error resulting from this should be present in Channels 1, 4, 6 (A, D, F). The effect is larger on Channel 2 and because of the change of balance on this channel could give rise to a possible systematic error of up to 2 radiance units, although the evidence we have from instrument performance is consistent with no such error having arisen.
- f. Change of gain on Channel 1. By orbit 2000 the gain of Channel 1 had changed by 10 percent. This may, of course, be due to deterioration of optical components. Supposing, however, that it is due to a loss of CO_2 pressure in the cell, the weighting function would change and for a 10 percent change in gain would move up by 20 percent in pressure or about 2 km. If this were the case, a systematic change should show up during the Wallops experiment.

Radiance map analyses for the December 1970-January 1971 stratospheric warming were presented (e.g. Fig. 10), in addition to examples of individual temperature retrievals. Space cross sections of temperature, based on retrievals, showed regions of an abnormally warm upper stratosphere. Time traces of SCR-observed radiances were compared with those computed from Datasonde and Arcasonde temperature profiles for Wallops Island (Fig. 11). For Channel 1, there were differences of several ergs/ between the SCR and Datasonde. A systematic radiance change corresponding to a loss of CO_2 pressure, mentioned above, was not evident.

The above discussion represents the presentations made on the first day of the Working Meeting. The second day was reserved for a comprehensive presentation of preliminary data comparison and a forum on all aspects of the comparison experiment.

PRELIMINARY DATA COMPARISON

Some information of the preliminary data comparisons was presented by A. J. Miller.

Although temperature as a function of pressure was the principal subject for comparison, an additional form of comparison was sought that would be independent of the scheme used to derive temperatures from the basic satellite radiance measurements.

NORTHERN HEMISPHERE

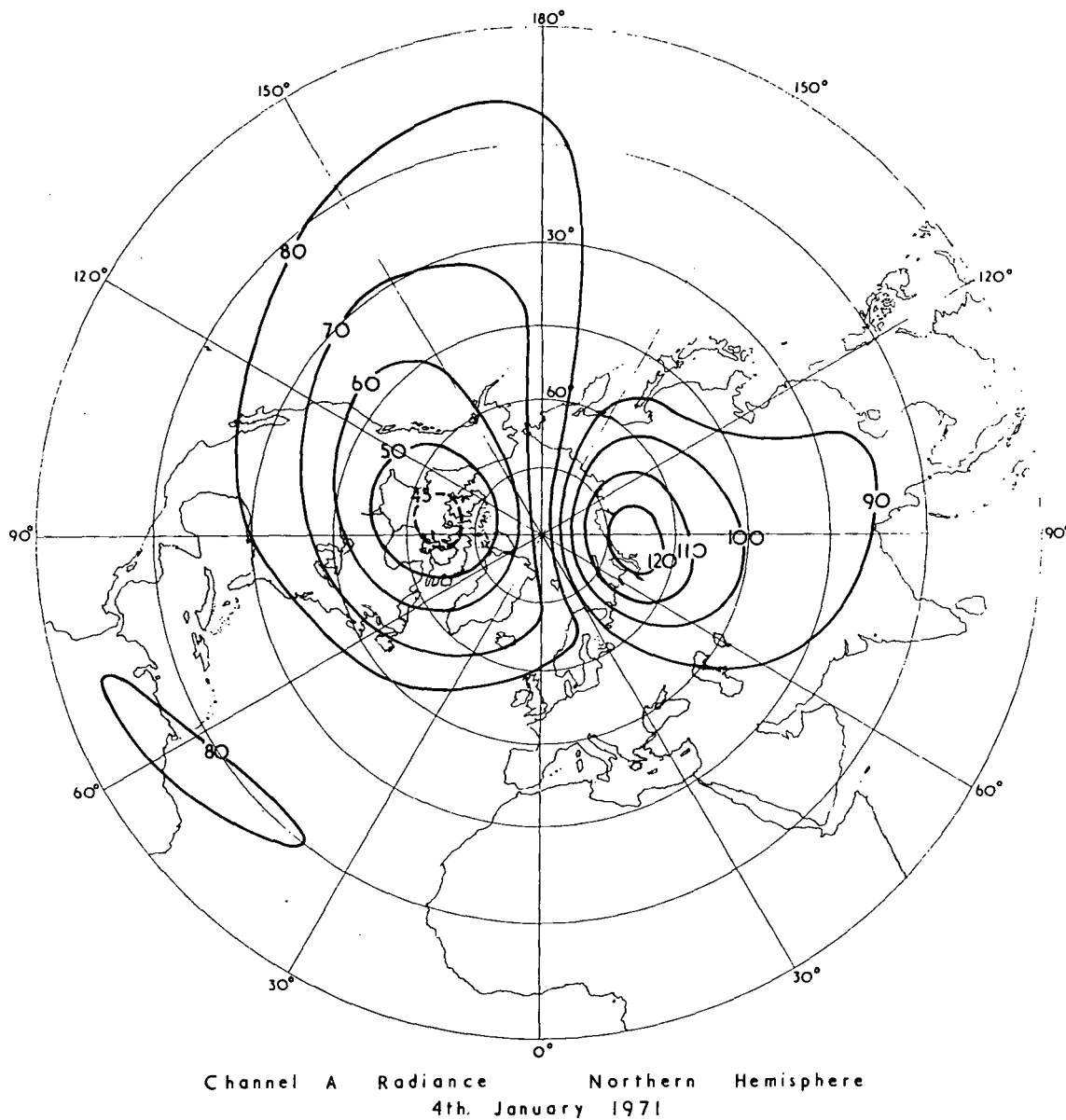


Figure 10. North Polar Stereographic Map showing isopleth of radiance ($\text{mW m}^{-2} \text{sr}^{-1} [\text{cm}^{-1}]^{-1}$) for Channel A for January 4, 1971. Map was derived from data of 12 orbits extending to 80°N.

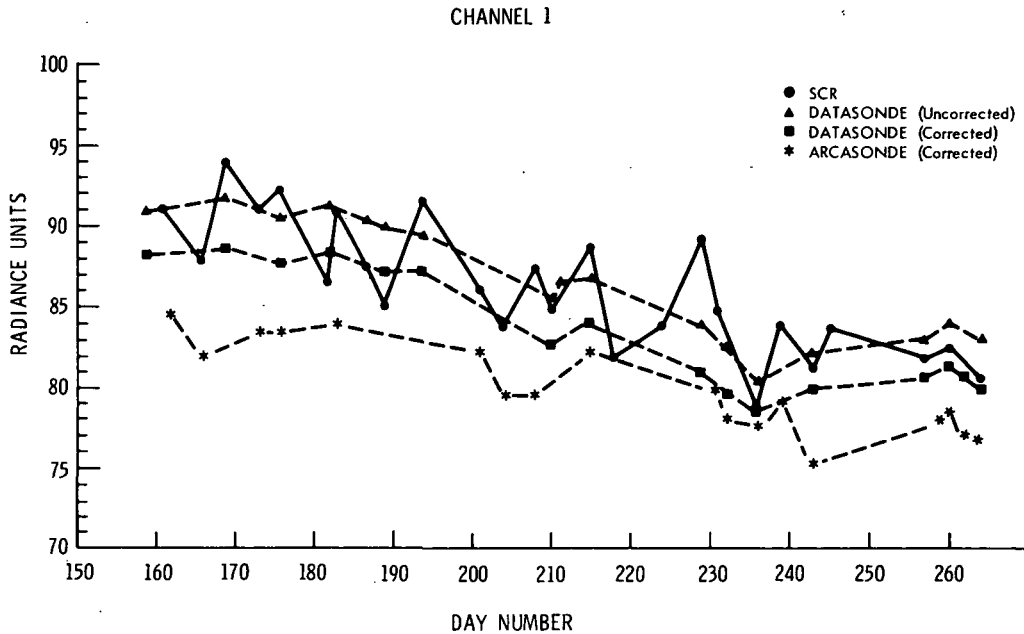


Figure 11. Comparison of Computed Radiances Measured by Channel 1 of SCR with Radiances Computed for Observations made by Data-sonde and Arcasonde Instruments.

The following equation states the radiative transfer equation for the atmosphere,

$$I(\nu) = \int_{P=P_S}^{P=0} B[\nu, T(P)] \frac{\partial \tau}{\partial \ln p} \partial \ln p + B[\nu, T(P_S)] \tau$$

where $I(\nu)$ represents the radiation emitted to space in a certain frequency range (in units of ergs/), B is the Planck radiance function, $\frac{\partial \tau}{\partial \ln p}$ is the derivative of the transmittance, commonly labeled the weighting function of the Planck radiance and the second term on the right is that portion of $I(\nu)$ received from the lower boundary.

The task in determining temperature retrievals is: given $I(\nu)$ in a certain number of frequency intervals or channels as measured by the satellite, to determine $B[\nu, T(P)]$ and therefore the actual temperature profile. On the other hand, since observations of $T(P)$ and therefore $B[\nu, T(P)]$ are available, it is possible to work in reverse and calculate from observed rocket temperatures the radiances that the satellite should see in each channel. This, in effect, removes the retrieval process from the comparisons and reduces the number of variables for consideration. A radiance difference of one erg/ is roughly equivalent to a difference of 1°C in the

weighted mean layer temperature. The final evaluations are made both for the radiance and the temperature differences.

Before the differences between the various instruments are considered, the nature of the systems themselves needs to be examined. Figure 5 presents the weighting functions, as defined above, for the eight channels of the SIRS-A experiment. The SIRS-B and IRIS experiments have similar weighting functions.

Previous research has indicated the need for certain adjustments to the data measured by both the small rocketsonde and the support rawinsonde. However, there are no universally acceptable correction schemes at this time. The radiosonde adjustment scheme lowers the reported temperature about 1°C between 100 and 50 mb (Ref. 20), where the data of the two sondes are merged. The adjustment lowering the reported Arcasonde 1A temperatures is that suggested by Drews (Ref. 21), and amounts to 6°C at 55 km decreasing almost linearly to 0° at 40 km. A more recent adjustment system suggested by Henry and Staffanson (private communication) was not available for this study. The effect of the difference between the two adjustments, however, is discussed later. No adjustment scheme has yet been generally accepted for the Datasonde instrument.

The first differences discussed were between the satellite SIRS-A measured radiances and those computed for the Arcasonde 1A and Datasonde I³ rockets (Table 4). Several additional comparisons were available for the period April 1969 - March 1970 prior to the formal experiment. For this earlier period the Arcasonde 1A unadjusted radiance differences are positive (the radiances calculated from the rocketsonde measured temperatures are relatively high compared to SIRS-A measured radiances) with the greatest disparity in Channel 8. The adjustment to the rocketsonde temperatures lessens the discrepancy in each channel, but does not account for the large difference in the topmost channel. The results for June-September 1970, however, surprisingly indicate an overall downward shift in the differences of about 2 ergs/. Inspection of the individual temperature and radiance observations for the period June-September 1969 versus June-September 1970 indicates that the rocketsonde-rawinsonde temperatures are lower by about 1°C , while the SIRS-A radiances increased by about 1 erg/. The reason for these differences is unexplained at this time.

The results from the Datasonde I instrument indicate that temperatures reported by this system are considerably higher than those of the Arcasonde 1A. This was suspected from earlier research (Ref. 1). The differences between the Datasonde and Arcasonde appear to be systematic but this bias may be due to the small sample size and/or possible variations in Datasonde manufacture during the earlier period. Datasonde II³ results show considerable improvement over the Datasonde I, but still indicate higher temperatures than the Arcasonde.

³The Datasonde I has thermistor bead mounted flush against mylar mount while on Datasonde II bead is raised. See earlier discussion.

TABLE 4

Mean Radiance Differences of Rocketsonde Minus SIRS-A.

<u>ΔR (ROCKETSONDE - SIRS A)</u>							
	UNADJUSTED			ADJUSTED			#OBS.
	<u>8</u>	<u>7</u>	<u>6</u>	<u>8</u>	<u>7</u>	<u>6</u>	
	<u>669 CM⁻¹</u>	<u>678 CM⁻¹</u>	<u>692 CM⁻¹</u>	<u>669 CM⁻¹</u>	<u>678 CM⁻¹</u>	<u>692 CM⁻¹</u>	
<u>ARCAS 1A</u>							
4/69-3/70	3.50*	1.11	0.52	2.51*	0.58	0.18	14
6/70-9/70	1.00*	-1.11	-1.11	0.02	-1.55*	-1.49	10
<u>DATAS I</u>							
4/69-3/70	5.93*	2.64	1.57				4
6/70-7/70	7.40*	3.70	2.10				3
<u>DATAS II</u>							
7/70-9/70	2.90*	-0.03	-0.20				5
* -significantly different from zero at 95% level							

* -significantly different from zero at 95% level

Results for SIRS-B are presented in Table 5. The Arcasonde 1A results are more consistent than for the SIRS-A Channels 8 and 7. The Datasonde I and II are both warmer than the Arcasonde, with the greatest differences for the Datasonde I at the highest levels. Unfortunately, the data from Channel 6 on SIRS-B have not been usable since launch.

The results suggest that the weighting functions for SIRS-B are more consistent among themselves than those for SIRS-A and that the Datasonde temperatures are significantly higher than the Arcasonde. The Datasonde II appears less biased than the Datasonde I.

TABLE 5
Mean Radiance Differences of Rocketsonde Minus SIRS-B.

<u>ΔR (ROCKETSONDE - SIRS B)</u>					
	UNADJUSTED		ADJUSTED		#OBS.
	<u>8</u>	<u>7</u>	<u>8</u>	<u>7</u>	
	669 CM^{-1}	678 CM^{-1}	669 CM^{-1}	678 CM^{-1}	
<u>ARCAS 1A</u>					
6/70-9/70	0.36	-0.17	-0.54*	-0.59*	20
<u>DATAS I</u>					
6/70-7/70	4.53*	3.15*			9
<u>DATAS II</u>					
7/70-9/70	2.30*	0.83*			13
<u>GRENADE</u>					
6/70-9/70	0.90* (0.08)	-0.03 (-0.38)	0.65* (-0.81)	-0.31 (-0.75)	3
<u>PITOT</u>					
8/70-9/70	-0.40 (1.01)	-0.39 (0.01)	-0.66 (-0.08)	-0.76 (-0.58)	3

* -significantly different from zero at 95% level

The grenade and pitot experiments can measure atmospheric parameters well above the altitudes of the meteorological rocketsondes. In this study the data extended down to about 5 mb (~ 35 km) and were merged with the Arcasonde-rawinsonde measurements of the same day to complete the temperature profile. Also presented in Table 5 are the grenade and pitot computations versus SIRS-B measurements. The results for the Arcasondes on the same days are noted in parentheses. In the case of the adjusted results, only the rawinsonde adjustment was included in the grenade and pitot profiles.

Results of the grenade comparisons, although few in number, suggest that their measured temperatures are higher than the same-day Arcasondes, and this disparity is increased by the Arcasonde adjustments. Greatest differences occur in the highest SIRS-B channel. The pitot experiments, in contrast, exhibit lower temperatures than the same-day Arcasondes, although the Arcasonde adjustments tend to bring the two measurements more into coincidence.

With this small sample of observations it is difficult to make definite statements concerning these systems, but the results suggest that the grenade temperatures tend to be higher while the pitot's tend to be slightly lower than those of the Arcasonde.

Since the IRIS radiances are measured with greater spectral resolution than the SIRS radiances, these data can be treated in a slightly different fashion. From the detailed IRIS data the radiance that IRIS would have seen in the SIRS-B channels was computed and compared with that which was observed by SIRS-B. Results in Table 6 indicate virtually no difference in Channel 8, but a disparity of over 4 ergs/ in Channel 7.

TABLE 6
Mean Radiance Differences of SIRS-B Minus IRIS.

	<u>ΔR (SIRS B - IRIS)</u>		<u>#OBS.</u>
	<u>8</u> <u>669 CM⁻¹</u>	<u>7</u> <u>678 CM⁻¹</u>	
6/70	-0.48	3.60	6
7/70	-0.02	3.70	5
8/70	0.60	4.63	6
9/70	1.02	4.50	5
AVERAGE	0.27 (± 0.19)	4.11 (± 0.31)	22

Unfortunately, operational difficulties with the SCR instrument have reduced the number of possible comparisons, but results obtained are shown in Table 7. Arcasonde-computed radiances are shown to be relatively low with respect to the SCR and hence the adjustments tend to increase the disparity. As would be expected from the previous satellite comparisons, the Datasonde II temperatures are lower than the Datasonde I, but higher than those of the Arcasonde. The differences shown for the Datasonde instruments, however, are obviously less than those for the Arcasonde.

Results for the SCR and the grenade and pitot experiments indicate that grenade temperatures are cold with respect to the SCR, but consistently high with respect to the same-day Arcasondes, this difference being as much as 4 ergs/ in Channel A for the adjusted profiles. One pitot temperature, however, is lower than the Arcasonde and the adjustment brings the two more into coincidence.

TABLE 7

Mean Radiance Differences of Rocketsonde Minus SCR.

	<u>ΔR (ROCKETSONDE - SCR)</u>								
	UNADJUSTED				ADJUSTED				
	A	B	C	D	A	B	C	D	#OBS.
<u>ARCAS 1A</u>									
6/70-9/70	-3.13*	-3.55*	-3.02*	-0.92*	-5.50*	-4.35*	-3.41*	-1.30*	16
<u>DATAS I</u>									
6/70-7/70	1.74	0.54	1.70	1.82					5
<u>DATAS II</u>									
7/70-9/70	-0.29	-1.49*	-1.86*	-0.11					7
<u>GRENADÉ</u>									
6/70	-4.2 (-6.0)	-2.8 (-4.0)	-3.3 (-3.5)	-0.5 (-0.6)	-4.2 (-8.3)	-3.2 (-4.6)	-3.6 (-3.8)	-0.7 (-0.7)	2
<u>PITOT</u>									
8/70	-6.1 (-4.1)	-4.6 (-3.9)	-4.0 (-2.9)	-1.0 (-0.1)	-6.0 (-6.4)	-5.2 (-4.7)	-4.3 (-3.6)	-1.2 (-0.7)	1

* -significantly different from zero at 95% level

The retrieval scheme used to derive temperature profiles from measured radiances has been discussed in a previous section. Since rocketsonde temperature profiles indicate small-scale perturbations that cannot be determined by the satellite temperature retrievals, mean-layer temperature differences for 100-10 mb (~ 16 -31 km) and 10-1.0 mb (~ 31 -49 km) were computed. These particular layers were chosen for evaluation because SIRS and IRIS have their maximum stratospheric information in the 100-10 layer and also because the relative invariance of the summer-time stratosphere allows the possibility of relatively accurate temperature determinations up to the stratopause (about 1.0 mb). For the SCR, an additional layer of 1.0-0.6 mb (~ 49 -53 km) was considered.

The results for the unadjusted Arcasonde 1A instrument are presented in Fig. 12 along with the 95 percent confidence limit. In the 100-10 mb layer, the Arcasonde-SIRS-B difference is very close to zero with the SIRS-A and IRIS temperature retrievals slightly higher and lower, respectively. From 10-1.0 mb, all three retrievals are relatively low, the SIRS-B gain exhibiting the least difference. In contrast, the SCR temperature retrieval is consistently high with respect to the Arcasonde temperatures, with the difference increasing to about 3° in the upper layer. Adjusting the Arcasonde-radiosonde profile by the techniques described above results in a relative reduction of the in situ temperatures as shown in Fig. 13. In the bottom layer, the differences

shift by less than 0.5°C while for 10-1.0 mb the temperature is about 1.2°C lower. The SIRS-B differences are not significantly displaced from zero in both atmospheric layers. Comparing the rocketsonde adjustment schemes utilized with that procedure recently derived by Henry and Staffanson, we note that the latter procedure would result in bottom-layer temperatures lowered still further by about 0.15°C , the intermediate level lowered by about 0.4° and the top level raised by about 1.5°C . In the case of the SCR, since it is already warm compared to the Arcasonde, either set of temperature adjustments tends to increase the disparity.

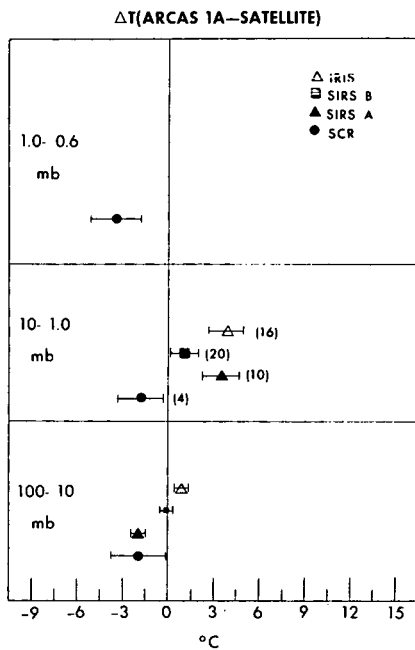


Figure 12. Mean Temperature Differences of Arcasonde 1A Minus Satellite Retrievals with 95% Confidence Limits. Numbers in parentheses indicate number of observations.

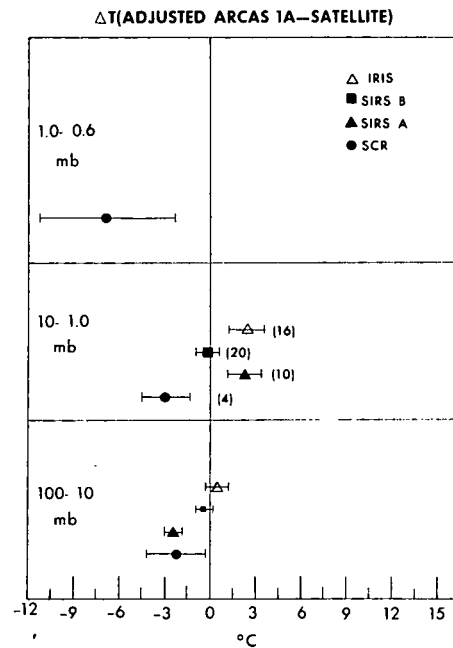


Figure 13. Mean Temperature Differences of Adjusted Arcasonde 1A Minus Satellite Retrievals with 95% Confidence Limits. Numbers in parentheses indicate number of observations.

Results for the Datasonde I are shown in Fig. 14. As anticipated, the rocketsonde temperatures are relatively high in both layers with respect to SIRS-A, SIRS-B and IRIS. This difference exceeds 3° in the lower layer and 6° in the intermediate layer. Comparing the Datasonde I results with those of the Datasonde II as shown in Fig. 15, we see that the former are relatively lower, although they are still relatively high compared to the Arcasonde. A statistical evaluation of the Arcasonde-SIRS-B, Datasonde II-SIRS-B differences showed them to be statistically different in both layers at the 95 percent confidence limit.

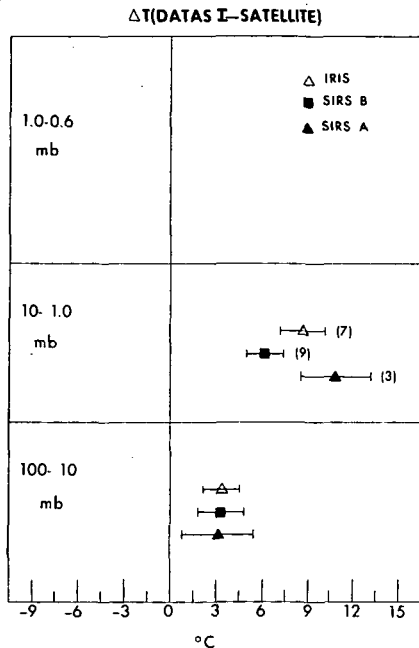


Figure 14. Mean Temperature Differences of Datasonde I Minus Satellite Retrievals with 95% Confidence Limits. Number in parentheses indicate number of observations.

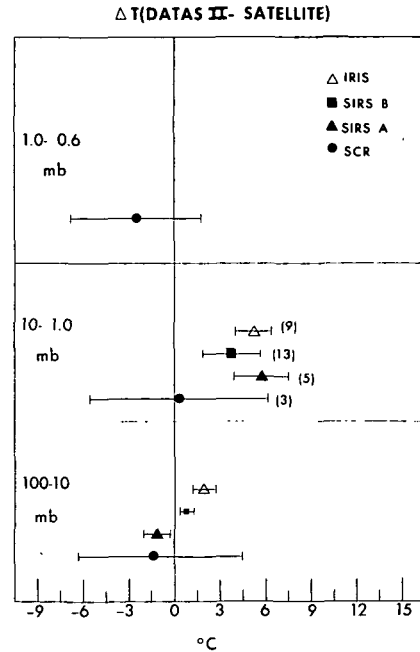


Figure 15. Mean Temperature Differences of Datasonde II Minus Satellite Retrievals with 95% Confidence Limits. Number in parentheses indicate number of observations.

Pitot and grenade results are shown in Figs. 16 and 17, respectively. However, the 100-10 mb layer observed temperature profile is that of the support Arcasonde 1A and rawinsonde. In the intermediate level the pitot temperature is relatively high compared to the SIRS-A, -B and IRIS retrievals although the difference is less than about 1.5°. The grenade temperatures, on the other hand, appear considerably higher than the satellite retrievals with the mean difference greater than 3°.

From the above discussions it may be concluded that:

- Since the radiance differences for Arcasonde 1A-SIRS-A were not constant over the period of a year, there may have been an undetected shift in either the rocketsonde or satellite or both instrument calibrations.
- Though the two SIRS instruments are similar in nature, the weighting functions for SIRS-B appear to be more internally consistent for the highest channels than do those for SIRS-A.
- SIRS-B radiances were as much as 4 ergs/ greater in Channel 7 than IRIS radiances. This difference is somewhat compensated for in the temperature retrieval process.

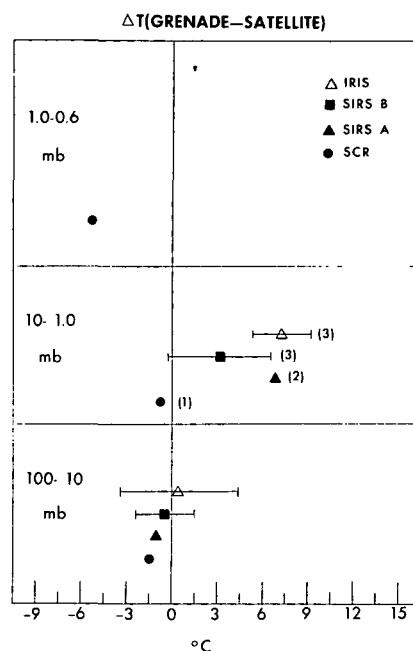
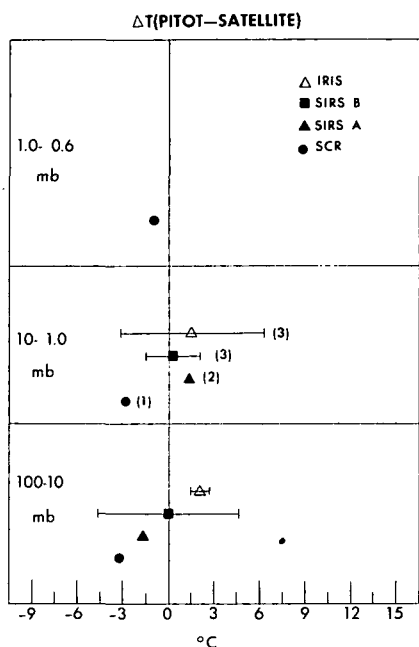


Figure 16. Mean Temperature Differences of Pitot Experiment Minus Satellite Retrievals with 95% Confidence Limits. Number in parentheses indicate number of observations.

Figure 17. Mean Temperature Differences of Grenade Experiment Minus Satellite Retrievals with 95% Confidence Limits. Number in parentheses indicate number of observations.

- d. The SCR temperature data are consistently higher than SIRS-A, SIRS-B, and IRIS. Moreover, the relative differences among the various rocketsonde systems appear to be maintained.
- e. The Datasonde I-measured temperatures are considerably higher than those from the Arcasonde 1A and Datasonde II.
- f. The Datasonde II measured temperatures are slightly higher than those from the Arcasonde 1A.
- g. The grenade soundings appear to yield temperatures which are slightly higher than those from the Arcasonde 1A.
- h. The pitot temperatures are slightly lower than those from the Arcasonde 1A.

DISCUSSION

As planned in the final agenda item, a general discussion followed the presentation of the data comparisons. In order to initiate the discussion, the group defined the main objective of the rocket-satellite comparison experiment; that is, to gain knowledge of the compatibility of measurements made with rockets and satellites, with the aim of applying this knowledge toward the improvement of the rocket sounding techniques and/or the transmittance functions used for the satellite instruments. The Chairman indicated that it would be appropriate for the participants to consider an even broader question, namely: What should be the role of the various rocket and satellite observing systems in the description of the upper atmosphere? To answer this question, one should not only recognize the advantages and limitations of the various sensing techniques, but also consider the demands and uses for high atmosphere data.

In lieu of a strictly chronological account of the ensuing discussion, therefore, the summary below provides an integration of the commentary under two general headings: Sounding Techniques, and Uses of the Data. This will be followed by the Chairman's review of germinal ideas in the discussion, together with some conclusions reached.

Sounding Techniques

Clearly, all of the in situ type sounding techniques used for the experiment had their limitations. The radiosonde is known to be a good atmospheric sounder up to about 20 km, but above that level it displays increasing errors in temperature measurement. Small meteorological rockets, such as the Arcasonde and Datasonde, yield temperature measurements above 20 km to about 50 km. Above 50 km, data from the grenade and pitot experiments can be useful.

There was general agreement among the participants that the experiment results showed that several types of rocket soundings were compatible, at least in terms of mean-layer temperatures. It was also agreed that the rocket will continue to plan an important role in sounding the atmosphere, and a complementary role to any future satellite observing programs. The rocket, however, is an expensive observing tool and efforts should be made toward the development of progressively less expensive rocketsondes. Concurrently, quality control methods in instrument manufacture and assembly should be stressed.

Satellite meteorology, of course, is yet at a very early stage. Developments are occurring very rapidly and predictions of future sounding refinements are indeed difficult to make. However, it is obvious that the fine temperature structure in vertical profiles that can be delineated with present-day rocketsonde techniques cannot be obtained from satellite data. Furthermore, it is doubtful that detailed structure will ever be obtained with the present design satellite sounders.

From the SIRS-type instrumentation, it was felt that temperature profiles can be obtained with a good degree of confidence in the stratosphere up to about 30 mb (24 km). Above that level, the information content decreases, so that the confidence level of the retrieved temperature also decreases. The information content of the SCR instrument extends up to about 45 km. It is planned that future SCR experiments will have the capability of extending this height to about 65 km.

A great advantage of the satellite is its capability of providing data on a global basis, especially over oceanic areas where the in situ networks provide their minimum data coverage. However, the disadvantages of present-day satellite observational systems should also be made clear. The techniques can, for example, only give limited information about diurnal variations, gravity waves, and other phenomena having small-scale structure in the vertical.

An important point of discussion revolved about the satellite transmittance weighting functions. It has been mentioned above that for the SCR the weighting functions have been empirically adjusted. For the SCR instrument on Nimbus 4 this procedure has not been carried through perfectly as the accuracy requirements on all the measurements involved are very high. For future SCR instruments, however, it is planned to improve the procedures and there is no reason why these methods cannot lead to the derivation of weighting functions which are as accurate as required. It was felt, then, that the satellite experimenters want to gain as much knowledge on the stratosphere as possible in order that the accuracy of the weighting functions may be checked. Thus, the role of the thermistor is to provide the most accurate temperatures possible. Improvements to the present-day rocketsondes (for example, the replacement of the film thermistor mount) may increase the accuracy.

Obviously, the differences among satellite measurements, implied by the rocketsonde-satellite comparisons, is of great concern. For example, there are systematic differences between SCR data and SIRS or IRIS data. Seeing that the experimenters for these instruments have used different methods to derive their weighting functions the fact that differences exist is not surprising. There is clearly room for careful comparison of methods between the different experimenters. A balloon experiment to measure weighting functions directly is being planned by the SIRS/SCR experimenters. In the case of the IRIS instrument, it should be noted, empirical methods based on radiosonde comparisons have been used to derive the weighting functions. A certain amount of the inferred disagreement between IRIS and SIRS has been explained and it is probable that the differences can be corrected. However, much work yet remains in the evaluation of the accuracy of each of the satellite instruments. In this connection such evaluation could conceivably be carried out with water vapor and ozone measured by IRIS.

Uses of Data

The uses of high-atmospheric data, whether measured by in situ methods or derived from satellite observations, may be classified according to research or practical requirements, although a clean separation of these is not generally possible. Under research requirements, we may consider data needed for describing the general structure and variability of the atmosphere. High-altitude analysis has been a valuable tool in these descriptions. Indeed, many of the large-scale features of the Northern Hemisphere stratosphere are known today from analyses based on relatively sparse rocket data.

Satellite data, especially from SIRS, even now are providing information for synoptic analyses of the Southern Hemisphere stratosphere, and for the Northern Hemisphere are complementing the more dense coverage from the rawinsonde network and rocketsonde stations. Processed SCR data are currently giving daily synoptic analyses of both hemispheres up to 45 km. It is important to have a knowledge of the resolution with which each type of data will provide, both in the vertical and horizontal. If the satellite data alone, for example, are not capable of determining small-scale structure, will these data in conjunction with rocketsonde information provide greater detail on this type of structure? Will the satellite data provide any new information in the tropics? Will observed winds be needed at all latitudes to ensure reliable analyses? These are questions that must be answered in due time.

Data are also needed for the study of the interactions between the lower and upper portions of the atmosphere, and for studying those structural changes which may be propagated upward and which may affect the high atmosphere (e.g., altering the conditions in the D-region which affect propagation of low-frequency radio waves).

Under practical needs, we may consider both operational and design problems. Some examples are: SST flight (lower stratosphere), space shuttle reentry heating (important especially at 50-70 km), radiowave propagation, very high altitude "constant-level" balloon flight, etc., and, conceivably, numerical weather prediction, insofar as there may at times be a significant stratospheric contribution to tropospheric pressure changes. Fulfilling these various data needs, with their varying priorities, depends on the resolution of the measurements made by rockets or satellites.

For some problems, either research or practical, satellite data should probably suffice; for others, rocket measurements will continue to be required. Tidal oscillations, for example, have large amplitude in the thermosphere, but rather small amplitude in the stratosphere and are not likely to be satisfactorily shown in the satellite data. On the other hand, for reentry heating calculations which take into account gross density changes in the mesosphere, it may not be necessary to know all the details in the temperature profiles; and here the satellite data can be made to yield the important information.

Users and potential users of satellite data must be kept aware of the rapidly developing techniques that could well change our future outlook. . For example, instrumentation is being developed for navigational applications. These require detailed data at very high altitudes. The horizon infrared sensors and microwave techniques possess the capability for providing the temperature profiles to very high altitudes.

Undoubtedly, there are many other ways in which to use present satellite data. The use of measured satellite data (radiances) as against the infrared temperature profiles (temperature retrievals) should also be fully investigated. Research on using radiances in numerical circulation models is already progressing. Maps of radiance data from SIRS and SCR are being analyzed on a daily basis. These maps are used to monitor the upper atmosphere in order to detect stratospheric warmings. Careful use of the radiance data can yield much more information than may be suspected, even though the radiance values represent rather thick, weighted atmospheric layers. However, the temperature structure may be modeled to determine characteristic patterns of radiance change.

The question arises as to the relative merits of the Rocket-Nimbus Sounder Comparisons in determining the compatibility of data from all the various meteorological rockets used throughout the world. Could, for example, each rocket station conduct its own comparisons by launching at the time of satellite overflight? If the satellite calibration remained constant this would form a constant base level for all comparisons. It was agreed that this idea has merit, although various technical problems would first have to be answered.

Review, Conclusions and Recommendations

The Chairman listed some principal ideas which evolved in the discussion as follows:

1. The experimental results (i. e., the radiance and temperature differences found in the Wallops Island comparisons) indicate that the differences between the satellite systems and rocket systems are of the same order of magnitude as the differences among the various satellite sounders and among the various rocket sounding systems.
2. The Arcasondes produce usable data to about 50 km, while the Datasondes appear to require modification of the design. The grenade and pitot methods are useful above 50 km.
3. SIRS and IRIS soundings provide usable data to 30 mb. SCR is capable of extending this limit satisfactorily to about 45 km. Further development hopefully will permit raising of SCR data to 60 or 70 km.

4. Satellites can provide useful information on gross atmospheric features, but presently do not describe small-scale features such as gravity waves, etc.
5. Further attention should be given to "volumetric" presentations of data, e.g., data which are considered representative of layers rather than precise points. It may also be possible to include uncertainty information.
6. Attention should be given to direct use of radiance data and comparison with conventional maps.
7. Development of methods to utilize both in situ and satellite remote sounding-type data for analysis and research should be continued.
8. Future sounding techniques should be taken into account, e.g., microwave and limb radiance methods.
9. The present comparison experiment should be extended and/or the present data should be studied further. Extension could mean more observations at the same location (Wallops), or sampling in other seasons and locations.
10. Another meeting should be planned to consider extending the comparison to lower altitudes.

Further discussion did not result in substantive changes to the foregoing items; although with regard to Item 3, it was noted that some difficulty had been encountered in the SCR retrievals when a strong vertical temperature gradient prevailed (in a stratospheric warming event).

With regard to Item 10, it was agreed that another meeting would be desirable, perhaps in the fall of 1972. Moreover, although the present group might not become actively engaged in satellite-radiosonde comparisons at lower altitudes, it could be recommended that such investigation be performed. (It was recognized that some work was already in progress.)

No definitive plan was presented for the continuation of the present experiment, except a general agreement that extension of the comparisons to other rocket locations was worthwhile.

The group clearly supported continued development of both satellite and rocket systems.

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APPENDIX I

AGENDA

Rocket/Nimbus Sounder Comparison (RNSC)

Workshop Meeting

March 23-24, 1971, NASA Wallops Station

- I. Welcome - R. L. Krieger, Director, Wallops Station
- II. Opening Remarks - M. Tepper
- III. Conduct of Experiment - J. F. Spurling
 - A. Timing of Soundings
 - B. Dissemination of Data
- IV. Rocket Sounding Systems Descriptions
 - A. Arcas and Boosted-Dart - F. J. Schmidlin (to include radiosonde techniques)
 - B. Acoustic Grenade Experiment - J. Theon
 - C. Pitot Probe Experiment - J. J. Horvath
 - D. Rocket Sounding Corrections - F. L. Staffanson
- V. Satellite Sounding Systems, Data Analyses and Comparisons
 - A. SIRS A & B - D. Wark
 - B. IRIS - B. J. Conrath
 - C. SCR - J. T. Houghton
 - D. Preliminary Data Comparisons - F. G. Finger and A. J. Miller
- VI. Discussion
 - A. Experimenters' Comments on Data Comparisons
 - B. Other Remarks
 - C. Summary of Comments and Remarks
 - D. Plans for Future

APPENDIX II

LIST OF ATTENDEES

Dr. B. J. Conrath	Laboratory for Planetary Atmospheres National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Mr. Richard Davis	National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23365
Mr. F. G. Finger	National Oceanic and Atmospheric Administration Upper Air Branch 3737 Branch Avenue Hillcrest Heights, Maryland 20031
Dr. R. A. Hanel	Laboratory for Planetary Atmospheres National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Mr. R. M. Henry	National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23365
Mr. Alfred C. Holland	National Aeronautics and Space Administration Wallops Station Wallops Island, Virginia 23337
Mr. J. Horvath	Space Research Building University of Michigan Ann Arbor, Michigan 48105
Mr. R. L. Houghten	Staff Scientist, Meteorology and Soundings Earth Observations Programs Office of Space Science and Applications National Aeronautics and Space Administration Washington, D.C. 20546
Dr. J. T. Houghton	Department of Atmospheric Physics Clarendon Laboratory University of Oxford Parks Road, Oxford, England

Mr. R. L. Krieger	Director Wallops Station National Aeronautics and Space Administration Wallops Island, Virginia 23337
Dr. Karen Labitzke	National Center for Atmospheric Research Boulder, Colorado 80302
Mr. J. Lienesch	National Environmental Satellite Service National Oceanic and Atmospheric Administration Washington, D.C. 20233
Mr. A. J. Miller	National Oceanic and Atmospheric Administration Upper Air Branch 3737 Branch Avenue Hillcrest Heights, Maryland 20031
Mr. Cary F. Milliner	National Aeronautics and Space Administration Wallops Station Wallops Island, Virginia 23337
Mr. Ray Minzner	National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Dr. W. Nordberg	Chief, Laboratory for Meteorology and Earth Sciences National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Mr. Richard Ormsby	National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Mr. R. Quiroz	National Oceanic and Atmospheric Administration Upper Air Branch 3737 Branch Avenue Hillcrest Heights, Maryland 20031
Mr. D. J. Ramsdale	Globe Universal Sciences, Inc. P.O. Box 12338 El Paso, Texas 79912
Dr. James M. Russel III	National Aeronautics and Space Administration Langley Research Center Hampton, Virginia 23365

Mr. F. J. Schmidlin	Weather Service Support Facility National Aeronautics and Space Administration Wallops Station Wallops Island, Virginia 23337
Dr. Shardanand	National Aeronautics and Space Administration Wallops Station Wallops Island, Virginia 23337
Dr. W. S. Smith	National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Mr. W. C. Spreen	Chief, Meteorology and Soundings Earth Observations Programs Office of Space Science and Applications National Aeronautics and Space Administration Washington, D.C. 20546
Mr. J. F. Spurling	Head, Meteorological Projects Section National Aeronautics and Space Administration Wallops Station Wallops Island, Virginia 23337
Dr. F. L. Staffanson	Dept. of Electrical Engineering University of Utah Salt Lake City, Utah 48105
Dr. Ken Stewart	British Meteorological Service Bracknell, England
Mr. George P. Tennyson, Jr.	Nimbus Program Earth Observations Programs National Aeronautics and Space Administration Washington, D.C. 20546
Dr. Morris Tepper	Deputy Director, Earth Observations Programs and Director of Meteorology Office of Space Science and Applications National Aeronautics and Space Administration Washington, D.C. 20546
Mr. J. S. Theon	National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771
Dr. D. Wark	National Environmental Satellite Service National Oceanic and Atmospheric Administration 3737 Branch Avenue Hillcrest Heights, Maryland 20031



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